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A STUDY OF THE SOURCE OF WATER SUPPLY FOR THE CITY OF DULUTH, MINNESOTA, WITH SPECIAL REGARD TO THE TREATMENT PROVIDED

Albert H. Stevenson

Environmental Health Center,
Cincinnati, Ohio

1949

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By

Senior Sanitary Engineer Albert H. Stevenson

* * * * * * * * * * *

1949
Federal Security Agency
Public Health Service
Environmental Health Center
Cincinnati, Ohio

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INTRODUCTION

Origin of Request:

Under date of October 20, 1948, Dr. A. J. Chesley, Executive Officer of the Minnesota Department of Health, addressed a letter to Surgeon General Leonard A. Scheele of the Public Health Service, requesting that consultation services be furnished to determine the necessity and desirability of providing additional purification for the Duluth public water supply which is obtained from Lake Superior. Under date of November 15, 1948, Assistant Surgeon General Mark D. Hollis replied that the Public Health Service would undertake such an investigation.

The writer was designated to investigate the problem. During the week of December 6, 1948, he conferred with Dr. Chesley; Mr. Herbert M. Bosch, formerly Chief, Section of Environmental Sanitation; and Mr. O. E. Brownell, Sanitary Engineer, Minnesota Department of Health at Minneapolis. Accompanied by Messrs. Bosch and Brownell, the writer visited Duluth and conferred with Dr. M. McC. Fisher, Duluth Director of Public Health; Mr. H. G. Tischner, Manager of the Duluth Water, Gas, and Sewage Disposal Department; and Mr. E. H. Ruble, engineer consultant to the city department. The writer inspected the pertinent physical facilities of the water and sewerage systems, reviewed water treatment plant operations, and obtained detailed analytical results. Additional, current data not collected at the time of the visit have been supplied by the City through the State Department of Health.

Acknowledgment:

The writer wishes to express his appreciation for the excellent assistance and many courtesies furnished to him by the Minnesota and Duluth officials without whose cooperation this report could not be made. He also gratefully acknowledges the valuable assistance rendered by Sanitary Engineer William E. Holy and Biologist John N. Wilson on the technical aspects of the report and by Draftsman Charles E. Hagedorn on the preparation of charts and diagrams.

Purpose of Report:

The study has been confined to a review of the adequacy of the waterworks facilities, water treatment operations and control including potential hazards which could be expected to affect the quality of the delivered water at the Lakewood plant. The report includes a discussion and conclusions as to the adequacy of present treatment methods, and recommendations for additional facilities and controls.

Historical:

In 1912, the Public Health Service made a study of the sewage pollution of interstate and international waters in the Great Lakes area with special reference to the spread of typhoid fever. Its report[1] covered an investigation of certain water supplies having as their source Lake Superior including that of the City of Duluth. The report points out the generally good quality of Lake

Superior water. It describes special features of Lake Superior such as depth which prevents wind action from disturbing the bottom at any great distance from shore and thereby permits intakes to be constructed at such depths that turbidity is absent most of the time. It points out the fact that zones of pollution which surround the water fronts of the lake cities vary with the effects of storm and flood and of winds and currents. These variabilities were studied at that time in connection with the possibility of pollution of the waterworks intake for Duluth, in view of the high incidence of typhoid fever in that city. Suggestions were made as to the safeguards which could be applied including several methods of disinfection. A study of the water quality to determine the need for filtration was suggested.

General Information:

The City of Duluth is located at the extreme westerly end of Lake Superior at the mouth of the St. Louis River. The city extends from Fond du Lac along the north shore of the St. Louis River, Spirit Lake, St. Louis Bay and Lake Superior, a total distance of 26 miles. It is situated on a rocky bluff extending inland from the lake an average distance of only 2.6 miles. The population of Duluth is currently estimated at 105,000 representing an increase of 4,000 since the 1940 census. A major distribution center with few large industrial plants, Duluth is served by eight railroads, nine shipping companies, and one airline.

Across St. Louis Bay from Duluth is Superior, Wisconsin, a city of 35,000. The two cities are known as the Twin Ports and handle an annual tonnage of more than 60,000,000 during an eight month lake shipping season. Most of this tonnage represents bulk grain and iron ore from the Mesabi Range.

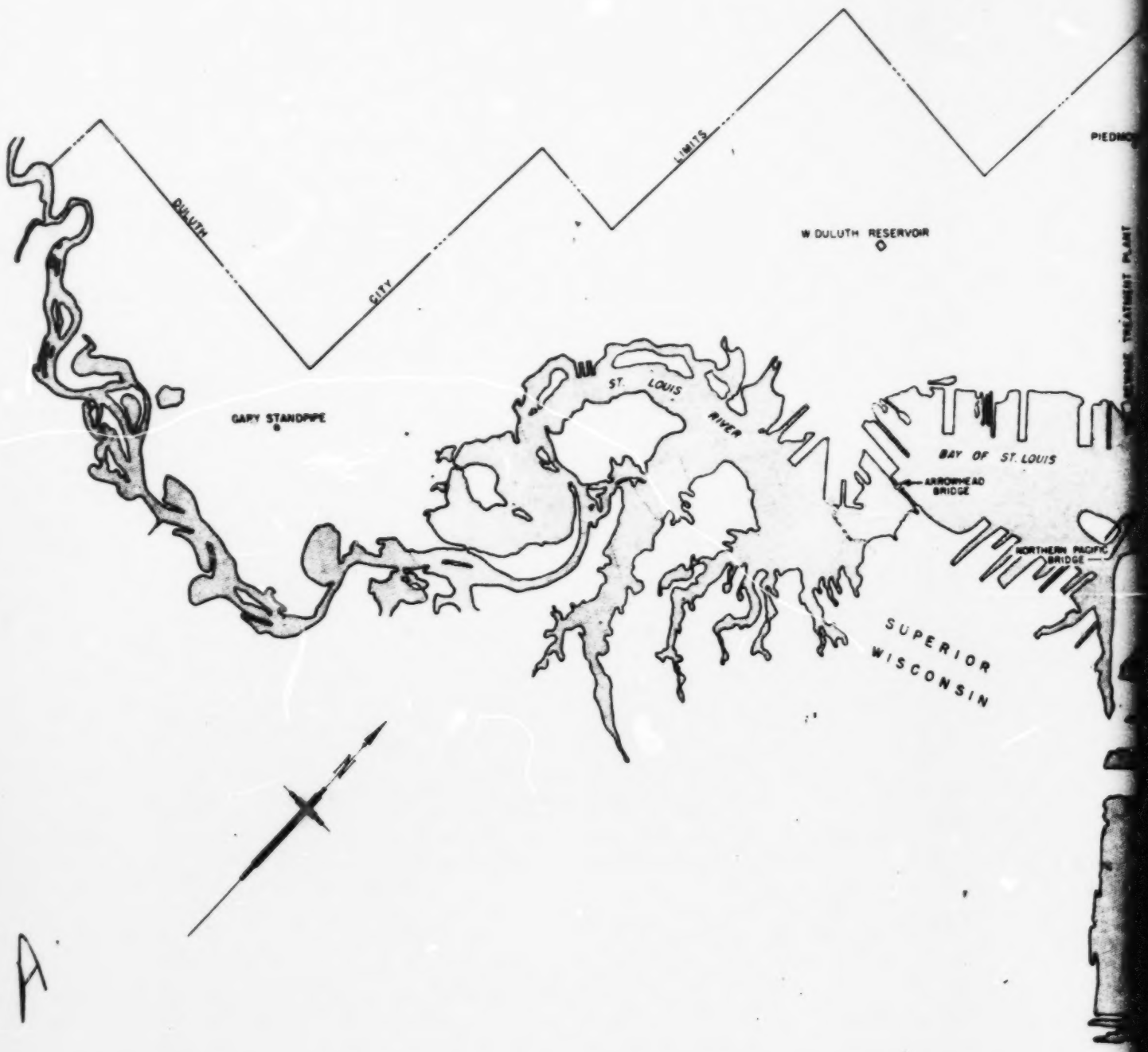
SOURCE OF SUPPLY

Water is obtained from Lake Superior at a point approximately nine miles northeast of the Aerial Bridge which separates the Duluth Harbor Basin from the Lake as shown in Figure 1.

Location of Intake:

The intake is situated about 1,500 feet out from the shoreline in 65 feet of water. It is located more than a mile from the shipping lanes used by ore boats. There are no built-up communities or other permanent major sources of pollution along the Lake Shore for a distance of 17 miles to the northeast. Talmadge River discharges into the Lake at a point about 2.8 miles below the intake. The City of Duluth lies to the southwest.

Prior to 1941, sewage from the City of Duluth was discharged without treatment into the harbor and directly into the lake at many points along the shoreline between the harbor and the waterworks intake. However, since that time intercepting sewers and pumping stations have been constructed to conduct the dry weather flow and part of the storm water to a sewage treatment plant located on the shore front of the Bay of St. Louis at 25th Avenue West. The sewage treatment plant is designed to handle an average flow of 12 mgd. and a maximum flow of 37.5 mgd. The treatment consists of mechanically cleaned bar screens,


DULUTH
CITY
LIMITS
W DULUTH RESERVOIR
GARY STANDPIPE
ST. LOUIS
RIVER
BAY OF ST. LOUIS
ARROWHEAD BRIDGE
NORTHERN PACIFIC BRIDGE
SUPERIOR
WISCONSIN
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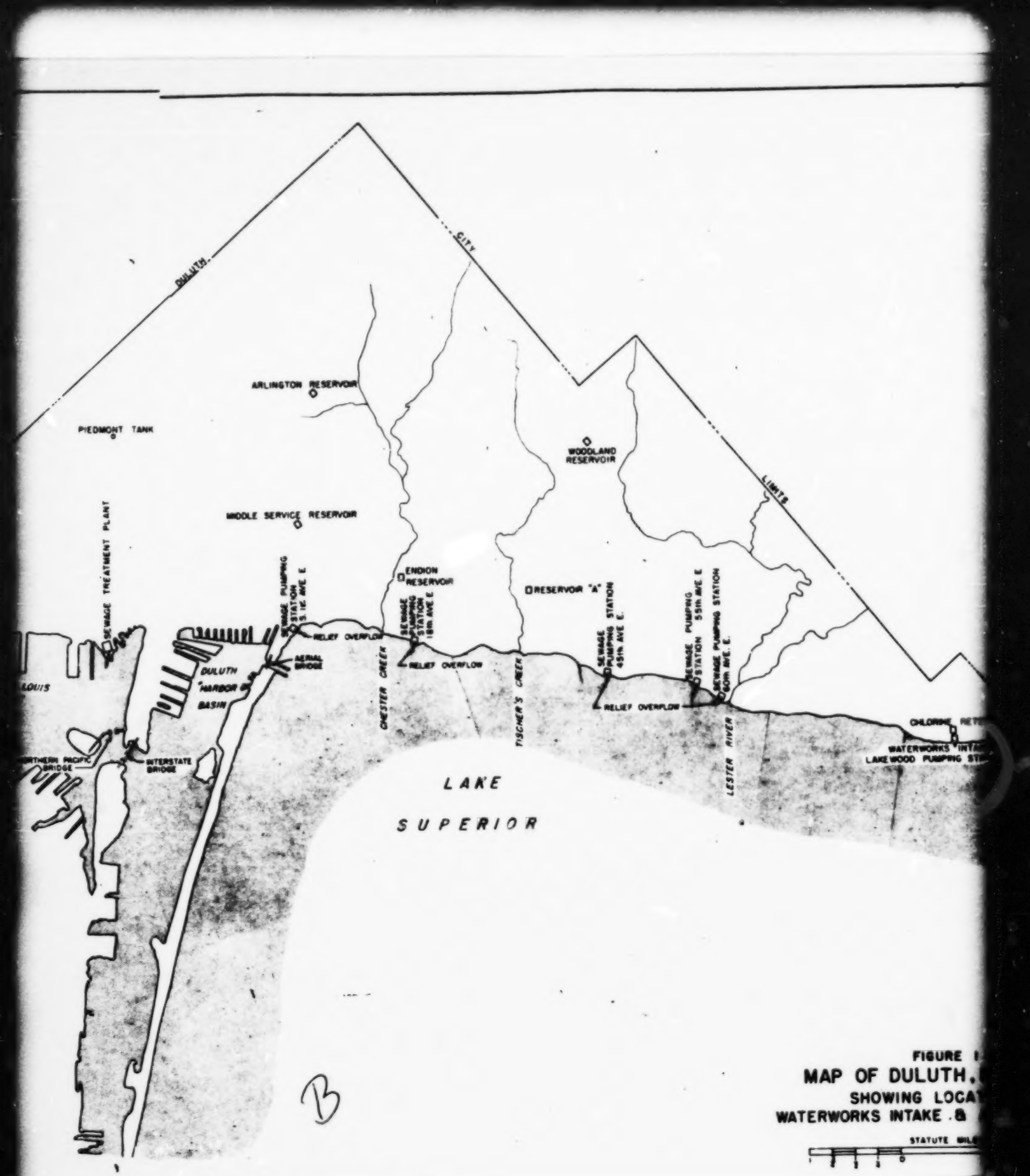

FIGURE 1
MAP OF DULUTH,
SHOWING LOCA
WATERWORKS INTAKE &
STATUTE MILE

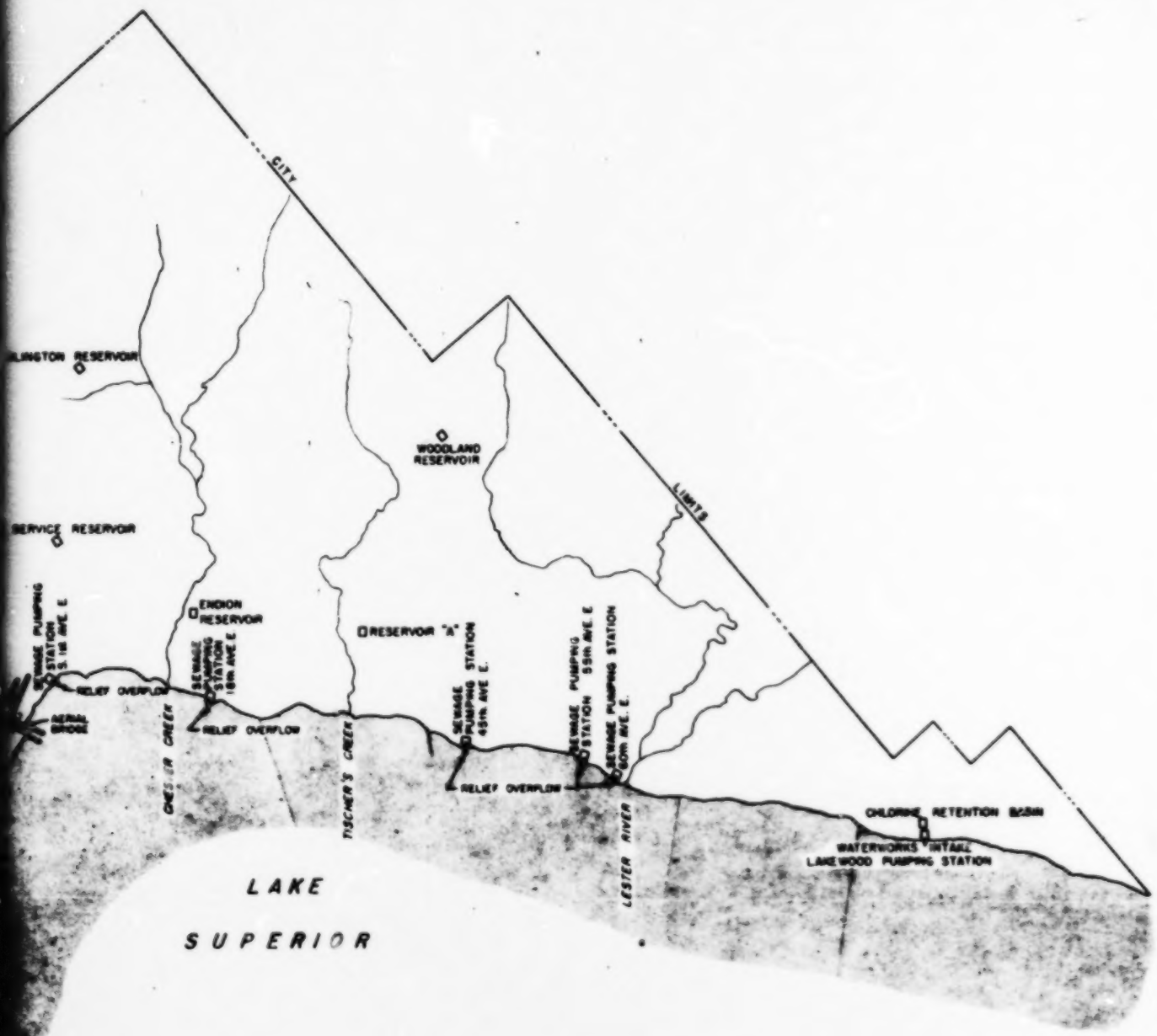

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FIGURE 1
MAP OF DULUTH, MINNESOTA
SHOWING LOCATION OF
WATERWORKS INTAKE & ADJACENT AREAS

passage through a grit chamber equipped with a continuous removal mechanism, two flocculators operated in series with provision for air agitation, mechanically equipped clarifiers, disinfection with chlorine, and final contact in a detention chamber. Suitable provision is made for the disposal of screenings, grit, and sludge from the clarifiers. The chlorinated sewage treatment plant effluent discharges into the Bay of St. Louis upstream from the Interstate Bridge and northwest of the Northern Pacific Railroad Bridge.

The construction and operation of these interceptor sewers and sewage treatment works has resulted in a general reduction of the pollution of the lake front waters between the Aerial Bridge and the waterworks intake as reported by the Minnesota Department of Health on a follow-up survey of the pollution of the St. Louis River in 1947-1948.(2) In this study the average coliform content (most probable number per 100 ml) of water sampled at the Aerial Bridge was 1600.

The interceptor system is designed to deliver combined sewage to a series of low lift sewage pumping stations along the shore front. There are five such stations between the waterworks intake and the Aerial Bridge as shown in Figure 1. Each station is provided with a storm overflow which may operate when surcharged during periods of storms. The 60th Avenue East Station is the closest to the waterworks intake, located about 2.8 miles to the southwest. The population tributary to this station represents relatively few families, however, there are frequent overflows at this point. At 55th Avenue East only a few houses are tributary to the pumping station and the relief sewer never has been reported to operate. The area served by these two stations and an adjoining area with a total potential connected population of 7,000 persons is tributary to the 45th Avenue East pumping station. Its overflow has been observed to operate only three times during the past eight years.

The 18th Avenue East station is located 6.5 miles from the water intake. It serves the populated Woodland area with an estimated residential population of 20,000 to 25,000. This overflow has operated frequently and it is proposed to construct a new sewer to relieve this condition. The South 1st Avenue East station at present receives sewage from a combined sewer. It is proposed to remove the storm water from this sewer and thereby eliminate storm water overflows at this point.

Lester River empties into Lake Superior at a point 2.7 miles southwest of the water intake. The river drains an outlying area of the city and passes through a park area. It is also reported that the effluents from a few household sewage disposal systems may discharge into this river. Pollution studies carried out by the Minnesota State Board of Health in 1928-29, and later in 1947-48, have indicated that biological fauna indicative of sludge deposits have been noted at the mouth of this river. It is believed, however, that these deposits represent principally decaying organic matter from surface wash carried to the lake.

Raw Water Quality:

The annual average and maximum monthly average raw water quality as measured by the confirmed coliform determination is shown for the nine year period 1939-1947 in Table I. These data are taken from the Annual Reports of the Duluth Water, Gas and Sewage Disposal Department and represent examinations made in the routine laboratory of the Department.

TABLE I
RAW WATER BACTERIOLOGICAL QUALITY
LAKEWOOD PLANT - DULUTH, MINNESOTA
(FROM CITY ANNUAL REPORTS)

Year	Number of Samples		Coliform MPN per 100 ml	
	Year	*Maximum Month	Annual Average	*Maximum Month
1939	598	50	30.7	232 (Sept.)
1940	601	54	19.3	58.8 (Oct.)
1941	599	52	8.4	22.8 (Oct.)
1942	594	50	5.2	18.0 (June)
1943	608	50	13.3	77.5 (Aug.)
1944	607	49	6.3	16.6 (Dec.)
1945	604	52	7.2	33.3 (Oct.)
1946	606	49	13.7	62.0 (June)
1947	606	50	11.2	68.1 (Apr.)

*Represents month of poorest raw water bacteriological quality.

It will be noted that the annual average coliform density (expressed as the most probable number per 100 ml) has not exceeded 13.7 since the interceptor sewer system and sewage treatment works have been in operation. Prior to 1941, these averages were 19.3 in 1940 and 30.7 in 1939. Similarly, a reduction has been observed in the maximum monthly average since 1939, the maximum of 77.5 in recent years occurred in August, 1943.

A frequency distribution of all raw water bacteriological results from both the routine and research laboratories (8,495 samples) in the 8½ year period, 1941 to July 1949, is shown in Table II. It will be noted that 34.3% of the time, all 100 ml. and 10 ml. portions were negative, representing a coliform density of less than 2.0 (MPN per 100 ml). The density was less than 35, 95.7% of the time and it exceeded 150 only 1.02% of the time. With the dilutions normally examined by the Duluth laboratories for the coliform test on raw waters, one 100 ml., five 10 ml., five 1 ml. and five 0.1 ml. portions, the maximum density of coliforms which may be estimated is 1600. In the 8½ years of record, only five of the 8,495 samples showed a density equal to or in excess of 1600.

Sudden variations from the normal of the coliform density of the raw water are not adequately shown by use of the frequency distribution analysis. This factor is better obtained by studying variations occurring during periods of relatively high raw water coliform densities. Referring to Table I and disregarding the years 1939 through 1941, which represent conditions prior to sewerage works improvements, we find the maximum month on the basis of the arithmetic average of individual results to have been August 1943, when the coliform density was 77.5 (MPN per 100 ml.). The next highest months were April 1947 and June 1946, with coliform densities of 68.1 and 62.0 respectively. It will be noted that all these averages are in the same order of magnitude. While these months represent the greatest average deviations from the normal, they do not demonstrate the occurrence of maximum bacterial variation. The frequency distribution of raw water bacteriological results by years (Table II) shows that maximum daily coliform densities or the greatest divergences from the normal occurred during the years 1946 and 1947. A comprehensive analysis of the two worst periods during

TABLE II

RAW WATER BACTERIOLOGICAL RESULTS

LAKEWOOD PLANT - DULUTH, MINNESOTA

Year	No. of Samples	Coliform MPN per 100 ml Ranges									
		All tubes negative	0.1-5	5.1-15	16-35	36-75	76-150	151-300	301-600	601-1200	1201-2400
1941	*1676	687	574	202	114	49	36	8	5		
	599	166	312	58	40	10	5	5	3	1	
1942	594	226	269	59	18	16	5	1			
1943	608	160	290	98	33	7	10	5	4	1	
1944	607	131	340	94	25	9	5	3			
1945	603	161	309	80	30	14	6	2	1		
1946	* 316	378	241	68	58	24	19	17	3	5	3
	606	134	323	78	37	16	8	6	2	1	1
1947	* 336	141	109	55	15	9	4	2	0	1	
	606	148	326	76	38	7	4	4	1	1	1
1948	* 350	161	120	43	22	1	3				
	600	185	322	66	20	1	6				
1949 (1)	* 180	80	85	12	1	1	1				
	314	155	133	21	3	2					
Total	8495	2913	3753	1010	454	166	112	53	19	10	5
	Per Cent:	34.3	44.15	11.91	5.34	1.96	1.32	.62	.22	.12	.06
Cumulative Per Cent:		34.3	78.45	90.36	95.70	97.66	98.98	99.6	99.82	99.94	100.0

*Examinations made in Lakewood Research Laboratory (other figures from routine laboratory)

(1) First 6 months.

those years was made. Hourly records of rainfall, temperature, wind, and turbidity were obtained in an endeavor to correlate these data with the bacteriological results. Figures 2 and 3 show graphically the variations in coliform density for these two periods.

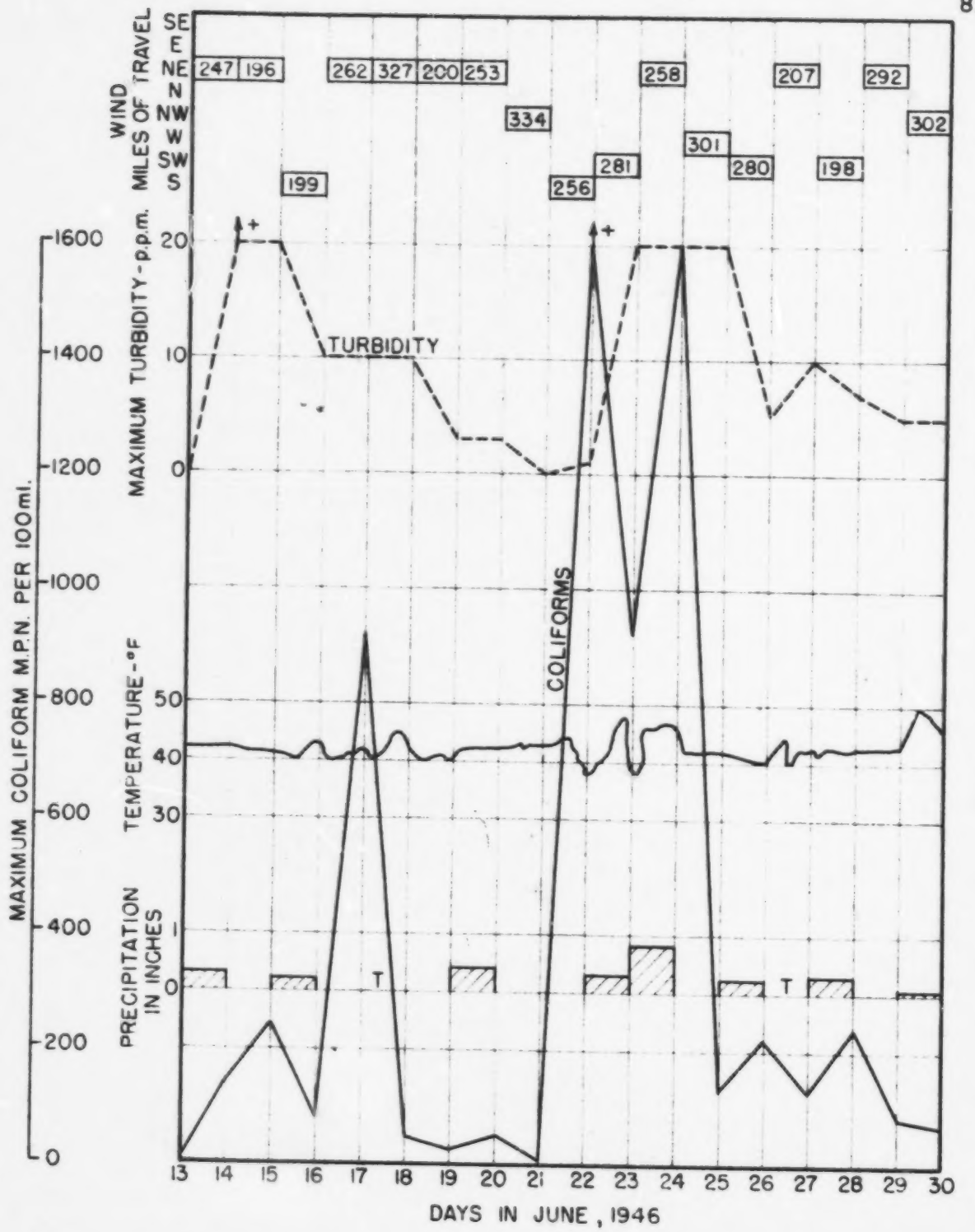
Inspection of the detailed daily records for these periods indicated that no single climatological factor appeared to be the cause of the higher-than-normal coliform densities observed. At the time of the most prolonged deterioration in raw water quality from June 14-28, 1946, there was a substantial amount of rainfall accompanied by generally northeast winds (prevailing wind) which resulted in an increase in turbidity of the raw water (the highest available turbidity standard, 20 ppm, was exceeded) and coliform densities which reached 1600 (MPN per 100 ml.). It is interesting to note that the water temperature fluctuated widely during this period, indicating that the lake waters were sufficiently disturbed to allow the upper strata of water to enter the waterworks intake. Even wider fluctuations in water temperature were observed on other occasions during the two year period with and without fluctuations in the coliform content.

Excluding the two periods noted above, the raw water quality was observed to exceed a coliform density of 200 (MPN per 100 ml.) on only nine days during the two year period. These results were observed with and without rainfall, and under various wind conditions, although the wind generally came from one of the northerly directions at such times. Frequently there was no accompanying rise in turbidity of the raw water.

The water was generally free of turbidity as is shown by the frequency distribution of turbidity results for the period January 1947 to July 1949, shown in Figure 4.

In summation, it may be stated that the quality of water delivered through the intake may be affected to a greater or lesser extent by the following: (a) meteorological conditions particularly rainfall resulting in relief sewer overflows, wind, temperature, storm water runoff from the Lester River area, and mixture of the upper and lower lake water strata; (b) flow of St. Louis River (containing sewage treatment plant effluent) into Lake Superior under Aerial Bridge; (c) discharge of wastes from lake vessels in the vicinity of the intake, and (d) the natural purification afforded by sedimentation in the lake. Possible leakage in the intake line always remains as a potential avenue for the entrance of shallower off shore water.

The record of the past 8½ years indicates that the raw water was generally of excellent quality from the physical, chemical, and bacterial standpoint for a surface water supply. The records indicate that on occasion the turbidity and/or coliform density do rise substantially, but the frequency of such occurrences is not great and the magnitude of the change in water quality is generally within the ability of water treatment plants of the type under consideration, exercising normal precautionary practices, to handle.

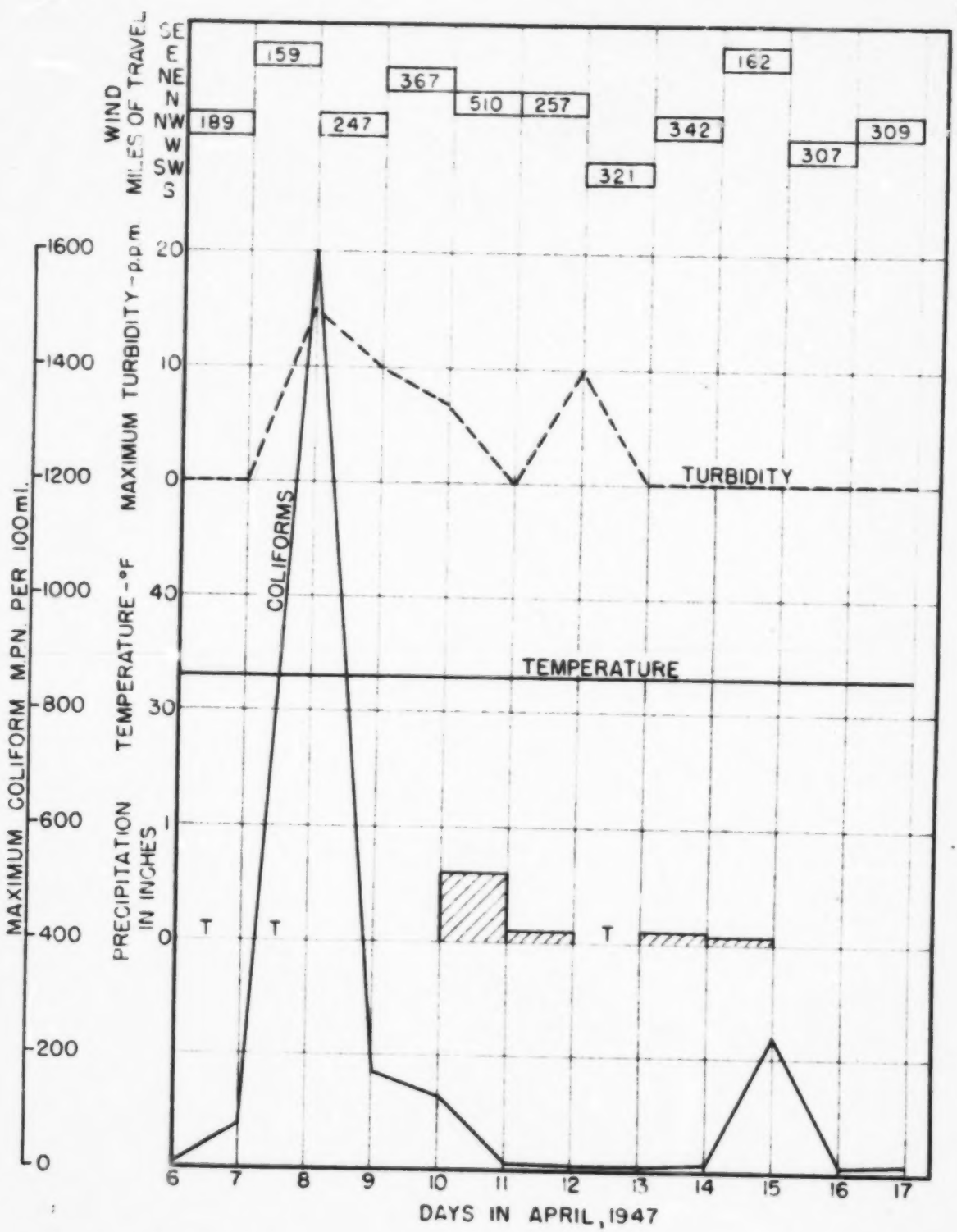


DATA FROM CITY RECORDS

FIGURE 2

VARIATIONS IN RAW WATER QUALITY FOR JUNE 13-30, 1946

(WORST PERIOD OF RECORD)



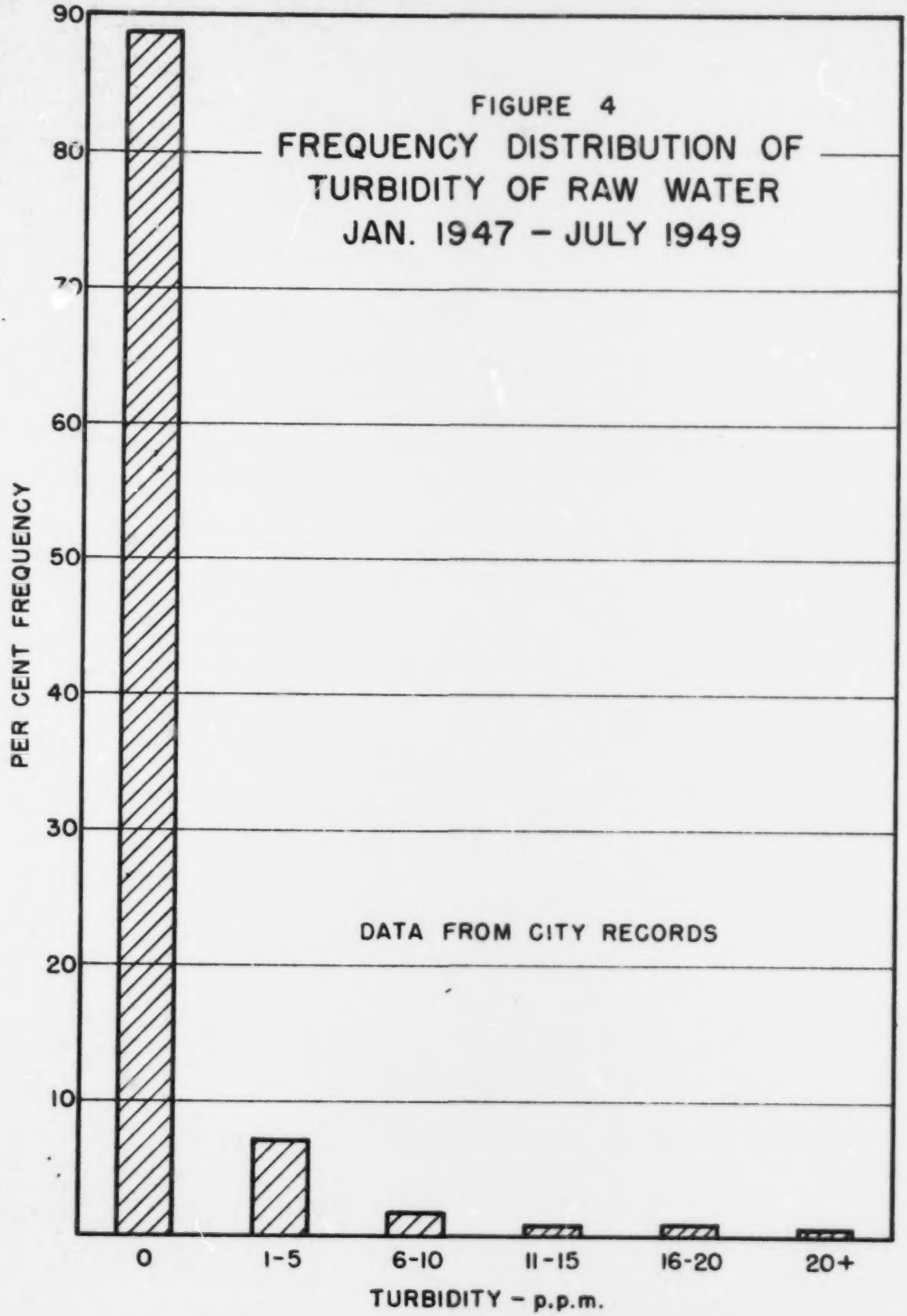
DATA FROM CITY RECORDS

FIGURE 3 .

VARIATIONS IN RAW WATER QUALITY FOR APRIL 6 - 17, 1947

FIGURE 4

FREQUENCY DISTRIBUTION OF TURBIDITY OF RAW WATER JAN. 1947 – JULY 1949



DETAILED DESCRIPTION OF PHYSICAL FACILITIES

The general layout of the Lakewood Station and appurtenant features are shown in Figure 5. This includes the intake works, treatment facilities, pumping units, and appurtenances.

Intake Works:

The intake of the Duluth water supply, constructed in 1900, is a 78" vertical pipe located 1,500 feet from shore in 65 feet of water. Surrounding and protecting this vertical pipe is a wooden crib backed up by rip rap. Water enters through the single opening at a depth of 55 feet and flows into a 60" riveted steel pipe equipped with bolted flexible joints. The bottom of the lake at this point is largely sand and gravel. At the time it was installed, a five foot layer of sand was placed over the 60" pipe from the crib to a point 770 feet off shore. As the pipe continues shoreward, it enters a nine foot trench dug into rock and is protected by rip rap until it enters a tunnel at a point 280 feet off shore. The pipe continues through the tunnel to an intake well which is located on land about 70 feet from the shoreline.

Water leaving the intake pipe flows through a traveling water screen which can be operated either as a fully automatic or as a manually controlled device. The screen is washed by treated water sprays located above the raw water flow line and the screenings are caught in two horizontal troughs and returned to the lake.

Chlorination and Ammoniation Equipment:

After passing through the screen, the water is chlorinated at the intake well. Chlorine is obtained in ton containers. Suitable handling facilities are available and two scales are provided for weighing the chlorine. Chlorine is piped to two 600 pound per 24 hour visible vacuum chlorinators which feed chlorine through a 1½" rubber lined cast iron pipe into the intake well. Three rubber lines for chlorine feed are available as spares.

A 300 pound per 24 hour visible vacuum chlorinator is maintained for post chlorination in the event that it is necessary. This unit is rarely operated except for maintenance purposes.

Two ammonia feeders each with a capacity of 80 pounds per 24 hours can be used for pre-or post-treatment. At the time of inspection, ammonia was being added to the water at the suction side of the high lift pumps.

Low Lift Pumps:

After chlorination, the water is pumped through a 36" discharge line equipped with venturi meter and thence through a 48" cast iron line into the detention basin. There are three 16 year old single-stage centrifugal low lift pumps which operate against a 48' to 51' average total dynamic head with rated capacities of 12,140 GPM (17.5 MGD); 14,500 GPM (20.9 MGD); and 14,500 GPM (20.9 MGD) respectively. One of the larger pumps is driven by a direct connected 25 cycle, 250 H.P. 2200 volt induction motor; the other by a 250 H.P. 60 cycle, 2200 volt induction motor. The smaller unit is driven by a 200 H.P. 60 cycle, 2200 volt induction motor.

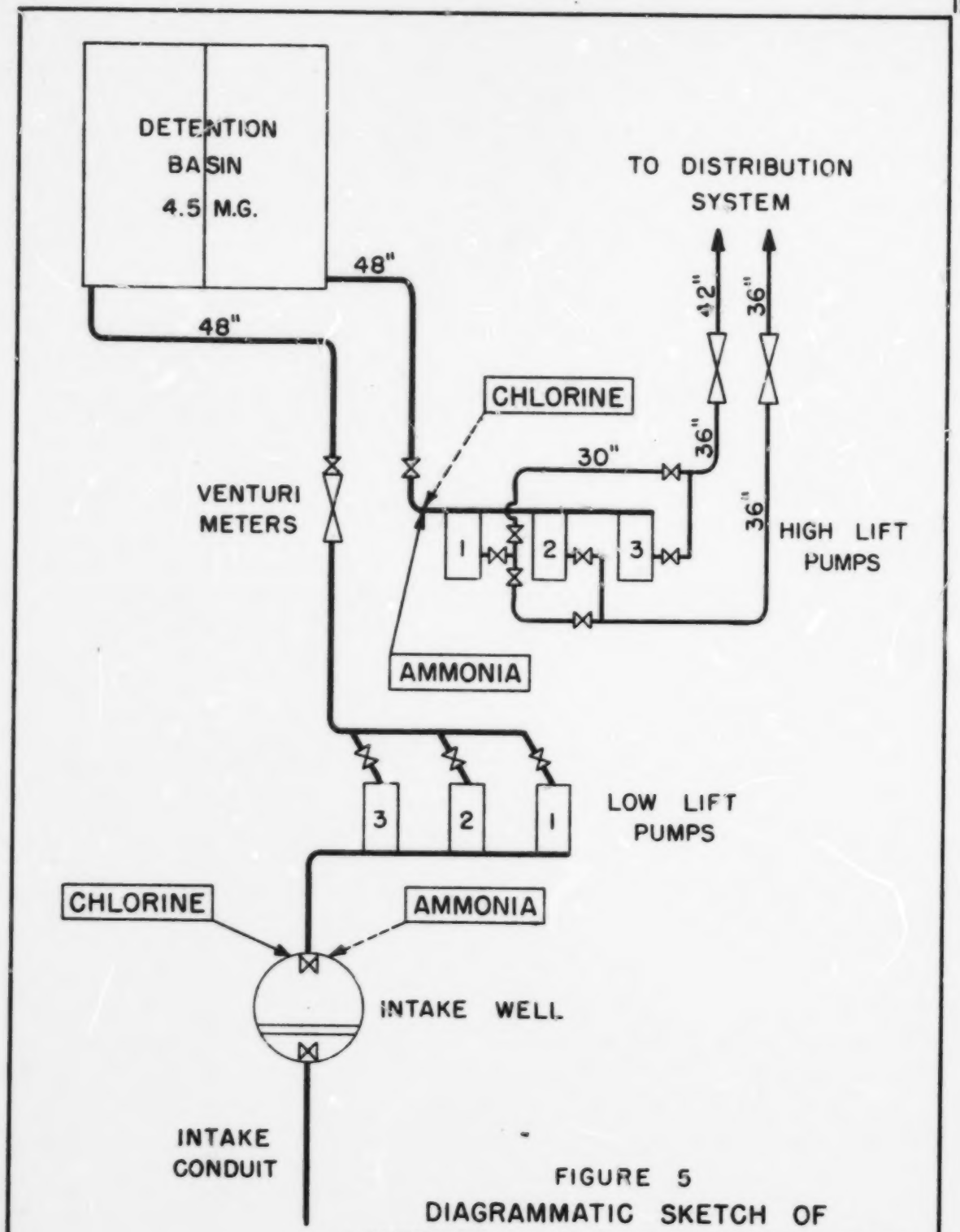


FIGURE 5
DIAGRAMMATIC SKETCH OF
LAKEWOOD PLANT & APPURTENANCES
DULUTH, MINN.

Settling and Detention Basin:

The settling and detention basin built in 1931 has a capacity of 4.5 M.G. It is 178 feet long by 158 feet wide with a maximum water depth of 21.25 feet. There is a central dividing partition which permits the operation of the two basin compartments either in series or in parallel. From the settling basin the water enters a 48" cast iron suction line through which it is delivered to the high lift pumps.

High Lift Pumps:

There are three two-stage centrifugal high lift pumps which operate against average total dynamic heads ranging from 273 to 291 feet. The pumps are rated at 15,100 GPM (21.8 MGC); 14,500 GPM (20.9 MGD); and 12,140 GPM (17.5 MGD) capacities respectively. Operations are controlled by an altitude valve at Reservoir "A" and may require pump heads as high as 312 feet. The largest pump is driven by a direct-connected, 1500 H.P., 2200 volt, 25 cycle, slip ring induction motor, the second unit by a direct-connected, 1250 H.P. 2200 volt, 60 cycle, synchronous motor with direct connected exciter, and the smallest pump by a direct-connected, 1000 H.P., 2200 volt, 60 cycle, synchronous motor with direct-connected exciter. In addition to these units, new 30 MGD low lift and high lift pumps were ready for installation at the time of the visit.

Water from the high lift pumps flows through two 30" cast iron mains equipped with Venturi meters and thence passes through one 36" cast iron and one 42" steel feeder into the distribution system.

Distribution System:

About 5/8 mile from the Lakewood plant the 36" feeder joins the 42" line. A single 42" main extends a distance of some three miles before reaching the major grid system which feeds Reservoir "A" and Woodland pumping station. Reservoir "A" has a capacity of 16.3 MG. From Reservoir "A" water flows by gravity or is pumped to ten reservoirs, elevated tanks, and standpipes with a total available capacity of 48 MG. These storage facilities serve the city on four different hydraulic operating levels.

CONSUMPTION DEMANDS

The daily average annual water pumpage and metered consumption since 1898, taken from the 1947 Annual Report of the Duluth Water, Gas and Sewage Disposal Department, are shown in Table III. The present average annual daily pumpage is about 16 million gallons. During the maximum month, the average daily consumption is generally less than 140% of the annual average. However, since the operation of the Lakewood pumping station is governed by an altitude valve at Reservoir "A", the peak rate of pumping for short periods occurs when two of the high lift units and corresponding low lift units are operating at the same time. Under these conditions, the pumpage rate may reach 30-32 MGD.

Although 30 MGD pumps are scheduled for installation, in the event of a breakdown or repair of one of these units, it may be assumed that pumpage rates up to 32 MGD may be expected to meet current peak demands including forseeable future needs.

TABLE III
RAW WATER PUMPAGE - METERED CONSUMPTION
Duluth, Minnesota

Year	Average Pumpage - MGD	Average Metered Consumption - MGD	Average Unmetered Use and Losses-MGD
1899	4.28		
1900	4.27		
1901	4.45		
1902	4.53		
1903	4.84		
1904	4.91		
1905	4.85		
1906	5.23		
1907	5.69		
1908	5.92		
1909	5.90		
1910	6.85		
1911	6.91		
1912	7.64		
1913	7.99		
1914	7.52	3.77	3.75
1915	6.80	3.73	3.07
1916	8.02	4.38	3.64
1917	8.46	4.45	4.01
1918	8.27	4.78	3.49
1919	8.18	4.93	3.25
1920	8.62	5.03	3.59
1921	8.75	4.92	3.83
1922	8.90	5.11	3.79
1923	9.98	5.59	4.29
1924	9.02	5.53	3.49
1925	9.65	6.18	3.47
1926	10.16	6.47	3.69
1927	11.00	6.53	4.47
1928	10.55	6.62	3.93
1929	10.58	7.05	3.53
1930	10.10	7.23	2.87
1931	9.46	6.72	2.74
1932	8.85	6.16	2.69
1933	8.99	6.26	2.73
1934	9.49	6.74	2.75
1935	9.56	6.71	2.85
1936	11.16	7.93	3.23
1937	11.14	7.98	3.16
1938	10.90	7.33	3.57
1939	11.14	7.61	3.53
1940	11.01	7.73	3.28
1941	11.48	7.92	3.56
1942	11.58	8.02	3.56
1943	12.41	8.52	3.89
1944	13.24	8.87	4.37
1945	13.66	9.11	4.55
1946	14.44	9.61	4.83
1947	15.20	10.28	4.92

ADEQUACY OF PHYSICAL PLANT AND EQUIPMENT

With the installation of the new 30 MGD low and high lift pumps at the Lakewood Station, the pumping facilities should be adequate and flexibility of operation assured.

During the critical period in late June 1946, when heavy raw water coliform loadings reached the plant, chlorine application as high as 400 pounds per 24 hours, representing roughly 2.3 ppm, were recorded while a single pump was in operation. A similar loading, while two pumps were in operation, would require up to 600 pounds per 24 hours to maintain appropriate residual chlorine levels in the treated water. In the event that one of the two 600 pound per 24 hour chlorinators available were out of service, the chlorinator would be operating at full capacity to meet this need.

Furthermore, it should be pointed out here that, at the present time, chlorination equipment is manually controlled and its operation must be synchronized with the pumps in use for effective control of the process. This practice introduces an element of unreliability inherent when dependence is placed on the human equation.

The detention basin has a volumetric retention period of 3.4 hours for the treated water when the flow is 32 MGD. Studies have indicated that, as is usual in tanks of this type, the actual flow-through time for the fastest moving particle is considerably less than the theoretical figure. It is estimated to be about one hour. Studies at the Duluth research laboratory have shown that the chlorine residual of 0.5 to 0.6 ppm of water leaving the basin is in both the "free" (at least 0.1 ppm.) and "combined" form. According to Butterfield [3], the hour retention period would be ample to provide 100% kill of the coliforms and other organisms he tested, at the pH range normally encountered in Lake Superior water. During low temperature periods, particularly, it is necessary to maintain a "free" chlorine residual of 0.1 ppm. or a "combined" chlorine residual of 1.5 ppm. Under these conditions the settling and detention basin is adequate for the treatment provided.

The possibility of a major failure in the three mile stretch of single feeder main to Reservoir "A" and the distribution system presents a hazard insofar as the adequacy of the entire system is concerned.

PLANT OPERATION AND LABORATORY CONTROL

Operating Practices and Plant Control Tests:

The pumps at the Lakewood Station are operated to maintain the water level at Reservoir "A". One or more sets of pumps is operated to meet the current demand requirements and to maintain the reservoir level. Chlorinators are operated concurrently to feed chlorine into the intake well. After low lift pumping and return from the settling and detention basin, about 0.2 ppm. ammonia is added to the water to convert all free chlorine to chloramine, thence the high lift pumps send the treated water into the distribution system.

The temperature of water at the intake is recorded. Samples of raw water are collected from the intake well at hourly intervals, during periods of pump operation, for comparison with turbidity standards. Although standards from 1 to 20 ppm had formerly been maintained, higher turbidities occurring in 1947 and 1948 resulted in the provision of a wider range of standards in December, 1948. Since that date the turbidity has not been recorded above 5 ppm.

For chlorination control, samples are collected at hourly intervals from the low lift pump discharge line during periods of pump operation. They are allowed to stand 10 minutes before orthotolidine is added. The standard residual chlorine test is made using La Motte comparators. Residual chlorine tests are also made on samples of water from the detention basin return line at similar time intervals.

Chlorinators are set to give a sufficient dosage to maintain 0.8 ppm residual chlorine in the low lift pump discharge line. This generally requires the application of 1 to 1.4 ppm of chlorine. As an added control the residual chlorine in the detention basin return line is watched closely. If it drops below 0.4 ppm a booster chlorinator is operated to feed into the high lift pump suction line. The operation of this post-treatment chlorinator is infrequent; it was used during the critical period on June 25, 1946.

The residual chlorine tests are run by plant operators. A research chemist checks the operators generally once per day, but not on a routine basis or set schedule. Generally the chemist makes no comment to the operator after his check test with a similar type comparator if his reading is higher than the operator's record. He reportedly has never obtained a lower reading than the operator.

Laboratory Control:

Two laboratories have been conducting frequent tests of the raw and delivered water quality at Duluth; the Routine Laboratory located in the center of the city and the Research Laboratory located at the Lakewood Station.

During periods of pump operation samples are collected routinely according to the following schedule for bacteriological examination:

Raw Water Samples from Intake Conduit

Research Laboratory	Routine Laboratory
12:30 P.M.	12:30 A.M.
	5:30 A.M.

Treated Water Samples from Detention Basin Return Line or High Lift Pump Discharge Line

Research Laboratory	Routine Laboratory
10:30 A.M.	12:30 A.M.
2:30 P.M.	5:30 A.M.
10:15 P.M.	
2:30 A.M.	
5:30 A.M.	

Additional samples are collected for special studies and at times of fluctuation in raw water quality. All sample bottles contain thiosulfate for immediate destruction of residual chlorine present. The procedures used are those outlined in Standard Methods.(4)

At the Research Laboratory, five 10 ml., five 1 ml., and five 0.1 ml. portions are examined routinely on raw water samples, higher dilutions are made if necessary. On treated water samples, five 100 ml. portions are examined. At the Routine Laboratory one 100 ml., five 10 ml., five 1 ml., and five 0.1 ml. portions are examined on all raw water samples; one 100 ml. and five 10 ml. portions on treated water samples.

At both laboratories all presumptive positive tubes including those showing a bubble of gas are transferred to brilliant green lactose bile broth for confirmation.

The Minnesota Department of Health officials stated that they were satisfied with the City's laboratory practices and would accept their bacteriological results.

In addition to bacteriological examinations, color, alkalinity, pH, odor, dissolved oxygen, and BOD determinations are made regularly in the Routine Laboratory. No nitrogen determinations are made on a routine basis. The ammonia nitrogen determination is of particular importance in determining the chlorine dosage required to obtain a "free" chlorine residual for the most rapid disinfection.

DELIVERED WATER QUALITY AS REFLECTED BY CITY AND STATE RECORDS

Physical and Chemical Quality:

The average annual physical and chemical characteristics of untreated Lake Superior water as reported by the city are shown in Table IV. Since no corrective chemical treatment is provided, the analysis of delivered water may be assumed to approximate that of the raw supply.

TABLE IV
PHYSICAL AND CHEMICAL QUALITY
UNTREATED LAKE SUPERIOR WATER
(From City Records)

Year	AVERAGE ANNUAL Turbidity ppm	Color ppm	Alkalinity ppm	Odor
1939	1 (6)	0	45.25	0
1940	0 (1)	0	45.1	0
1941	0 (1)	0	44.5	0
1942	0.3 (4)	0	43.7	0
1943	1 (6)	0	43.5	0
1944	0.6 (2,3)	0	43.8	0
1945	0.2 (2)	0	43.9	0
1946	0.5 (4.3)	0	43.2	-
1947	1.5 (9.3)	0	42.4	-

( ) Figure in brackets represents maximum month

Samples of untreated water collected November 20, 1946, and October 16, 1947, were examined by the Minnesota Department of Health laboratory. The results of these analyses expressed as parts per million, except as noted, are shown below:

Determination	Samples Collected	
	November 20, 1946	October 16, 1947
Turbidity	0.5	1
Color	0	3
Total hardness	40	60
Alkalinity	48	50
pH (in pH units)	7.9	7.4
Iron	0.01	0.08
Manganese	< 0.05	0
Chloride	1.3	1.1
Sulphate	0	0
Fluoride	0	0
Nitrate Nitrogen	-	0.2

These data indicate that there is very little change in the physical and chemical characteristics of the water and that, for the tests made, the water meets the Public Health Service Drinking Water Standards. However, it should be pointed out here that the occurrence of manganese in concentration of 0.01 ppm or more may give a false reading in the orthotolidine test for residual chlorine.

Bacteriological Quality:

Since the bacterial indicator is of the most sanitary significance insofar as this study is concerned, more consideration has been given to this aspect of the problem. The raw water quality has been described in an earlier section of this report and is summarized in Tables I and II.

The treated water, as delivered from the Lakewood Station, has been examined for coliforms in accordance with the Standard Methods.(4) The results of examinations of 11,937 samples during the period January 1941, through June 1949, are given in Table V. During this entire period only 19 portions were confirmed as positive for coliforms. Since 1945, only nine portions from the 3943 samples examined showed the presence of gas in the confirmatory medium and all nine were 100 ml. portions. None of these positive results occurred at or immediately following periods of unusually high raw water coliform densities. The frequency of sampling and bacteriological results indicate that the delivered water has been of excellent bacterial quality and well within the standards of the Public Health Service for drinking and culinary water.(5)

In earlier reports (6) consideration has been given to the occurrence of gas-former organisms (which do not necessarily confirm as members of the coliform group). A review of presumptive positive coliform results on 1471 delivered water samples collected during the calendar year 1947, revealed that 145 of the 7355, 100 ml tubes examined (2.0%) were positive. All of the presumptive positive tubes were transferred to brilliant green lactose bile, but only eight of them (5.5%) were confirmed. The majority of the presumptive positive results occurred in the winter and spring of the year during a period of the most prolonged turbidity in the memory of water department personnel.

TABLE V
DELIVERED WATER COLIFORM RESULTS
LAKEWOOD PLANT - DULUTH, MINNESOTA

Year	No. of Samples	Number of Portions Positive 100 ml and/or 10 ml	Remarks
1941	* 1847	4	Research laboratory examines 5-100 ml portions for each sample
	594	2	
1942	597	0	
1943	607	3	Routine laboratory examines 1-100 ml and 5-10 ml portions for each sample
1944	606	1	
1945	603	0	
1946	* 909	1	During this period all confirmed positive results were in 100 ml portions only.
	604	0	
1947	* 1471	8	
	608	0	
1948	* 1729	0	
	602	0	
1949 (1)	* 846	0	
	314	0	
Total	11,937	19	

* Examinations made in Lakewood Research Laboratory (other figures from routine laboratory)

(1) First 6 months.

A spot check of presumptive positive results observed on delivered water samples collected during 1948 and the first six months of 1949, indicated a substantially lower percentage and none of the portions confirmed in the secondary media.

The percentage of non-confirming gas-formers is considerably lower than are generally found in most surface water supplies, however, it would be highly desirable to isolate the resistant organism or organisms producing these results and to determine their sanitary significance.

Biological Quality:

No detailed biological studies or microscopic examinations of Duluth water have been made in recent years. Apparently, no odor complaints are received by the Department and, as shown previously in Table IV, no odors were recorded by the Routine Laboratory between 1939 and 1945. During the period July 1939, through March 1941, an extensive study was made of the plankton content of the raw and treated waters. Samples were collected, centrifuges, and examined microscopically on a daily basis. The predominant species were found to be diatoms which constituted 74 to 99% of the total observed. The second most abundant organisms were the protozoa, Dinobryon.

A detailed review of the plankton differentions during one of the months of highest concentration, September 1939, was made by Biologist John N. Wilson. During this period, the total diatoms ranged from 140 to 3000 areal standard units per ml. with four of 29 samples greater than 1000 and 18 greater than 500. Experience has shown that for some organisms at 500 to 1000 areal units per ml. tastes may be expected under certain conditions; at concentrations greater than 1000, tastes and odors generally occur. The above data indicate that with the concentrations found, slight tastes may develop which could be attributed to diatoms, but they would not be serious.

Although Dinobryon has been found to produce fishy tastes in water supplies, the concentrations ranging from 0.12 to 106 areal standard units per ml., found in September 1939, the maximum during the study, would not be sufficient to produce appreciable tastes.

DISCUSSION

Over the past years the Public Health Service has conducted extensive studies of the efficiency of the variqus processes used in the purification of public water supplies. The results of these studies have been published. The basic fundamental principles which they set forth, along with other adaptations, have served as a guide in the development of measures for the sanitary control of our public water supplies. These principles have remained unchanged with the passage of time. Their interpretation and application to today's problems in the water supply field, however, necessarily must reflect the progress achieved in this science.

Chief among these accomplishments is the progress made toward a better knowledge and understanding of the chlorination process of water treatment. The chemistry of chlorination has been determined. The mechanics of chlorine's

bactericidal action have been studied and determined. The philosophy of its use as a safeguard or as a treatment process for public water supplies, however, remains a moot question. The public health viewpoint supports its use as a safeguard following prior sanitary treatment of the water supply. Sanitary treatment as used in this sense infers the employment of natural or conventional artificial processes of purification to deliver a water of minimal bacterial density to which chlorine may be added to protect against unforeseen contingencies. This does not preclude the use of chlorine as a prior treatment process.

In his studies of water purification, Streeter(7) developed limiting raw water coliform indices per 100 ml. for water of the Ohio River and Great Lakes from which effluents meeting the primary requirements of the Public Health Service Drinking Water Standards could be produced by the average plant of the more efficient type using various combinations of treatment. For marginal chlorination alone this limiting value was found to be 80 for Ohio River water and 50 for Great Lakes waters. He points out the various limiting factors involved in the general application of these limits.

The limits for coagulation, sedimentation and rapid sand filtration without chlorination were determined to be 80 for Ohio River waters and 60 for Great Lakes waters or practically the same as for marginal chlorination alone. Limits for prechlorination settling and post chlorination, as is currently practiced at Duluth, were not considered. However, Streeter(8) does point out "that systematic raw water prechlorination, which has been used at East Chicago and Sandusky, may constitute a further possible measure permitting the successful bacterial treatment of raw waters more highly polluted than are represented by the foregoing coliform maxima" in considering loading to be handled by filtration plants.

With this background, the results of the investigation of the Duluth water supply problem may be summarized as follows:

1. The bacteriological examination of samples of water collected from the source of supply, Lake Superior, at the intake from 1939 to 1947 inclusive showed an average annual coliform density (MPN per 100 ml.) ranging from 5.2 (1942) to 30.7 (1939). The maximum monthly average during the same period was 232 (September 1939). Certain corrective measures were taken in regard to the collection and disposal of sanitary sewage from 1939 to 1941. The maximum month following these improvements occurred in August 1943, when an average coliform density of 77.5 was observed.

2. Further statistical analysis of bacteriological data for the raw water covering the period of 1941 to July 1, 1949, (8,495 samples) indicated coliform densities of less than 35, 95.7% of the time and in excess of 150, 1.02% of the time. In the 8½ year period only five of the 8,495 samples showed a density equal to or in excess of 1,600. A detailed study of the daily variations in coliform density of the raw lake water for the years 1946 and 1947, the two years when maxima average annual coliform densities occurred subsequent to the installation of sewerage improvements, does not indicate loadings beyond the potential limits of present water treatment facilities.

3. The bacteriological studies which represent only one component of the sanitary survey, does develop certain criteria for degree of treatment to be employed. Other sanitary factors, however, also must be considered in evaluating the conclusions.

4. Contributing sewage pollution from the drainage area in the vicinity of the waterworks intake has been controlled to a great extent by the construction and installation of sewerage works.

5. Turbidity observations from January 1947 to July 1949, showed that the raw water turbidity exceeded 10 ppm, the suggested limits for drinking waters,(4) less than 2% of the time. The maximum turbidity was not recorded as the standards used over the greatest part of this period did not exceed 20 ppm.

6. The possibility of chance pollution of the lake water in the vicinity of the waterworks intake by vessels discharging wastes and by sewage-laden ice is recognized.

7. Deterioration in raw water quality of similar lake supplies, where efforts have been made to control lake pollution (e.g. Chicago), demonstrate the necessity of pointing out the fact that conclusions reached today represent judgment based on present conditions only.

8. The physical and chemical characteristics of the delivered water meet the requirements of the Public Health Service insofar as tested.

9. Biological data for the raw and treated water may be interpreted as of only slight public health significance. The fact that during certain seasonal periods a slight taste may develop that can be attributed to diatoms is pointed out in the body of the report.

10. Of 11,937 samples of delivered water examined bacteriologically (1941-1949) only 19 portions were found to be positive. The bacteriological quality of the delivered water at the present time is excellent.

11. The incidence of enteric disorders and deaths in Duluth has been reviewed with attention directed toward the water supply as the possible mode of transmission. No direct conclusions could be drawn but all evidence seemsto eliminate this possibility.

CONCLUSIONS

As a result of the foregoing observations, it may be concluded in principle that:

1. Prechlorination and settling constitutes a satisfactory treatment process for the raw water studied at this time.

2. Post-chlorination provides the necessary factor of safety for the treatment process.

3. Further protection of the waterworks intake should be provided and present treatment facilities and operation and control practices should be further strengthened by following the recommendations outlined in this report.

4. Continuous vigilance is required to assure that water intake is protected from possible pollution through later municipal or industrial expansion and that the intake line is free from leaks.

RECOMMENDATIONS

Pertaining to Protection of the Source of Supply

1. Proceed with the construction of suitable sewerage facilities to eliminate combined sewage relief overflows at sewage pump stations east of the Aerial Bridge during storm periods.

2. Eliminate discharge of household sewage disposal system effluents into Lester River and maintain vigilance to assure that new outlets are not installed.

3. Provide adequate sewer facilities in the residential areas being built up in the vicinity of the Lakewood Station to assure that all domestic sewage will be tributary to the city interceptors.

Pertaining to the Treatment Facilities

4. Provide an additional chlorinator for pre-treatment in order to assure sufficient capacity to meet peak chlorine demands under maximum pumpage rates when one chlorinator is out of service. The installation of a third 600 pound per 24 hour chlorinator is suggested.

Pertaining to Operation and Control Practices

5. Install automatic controls to insure that chlorinators are in operation before pumps are operated at Lakewood.

6. Make ammonia nitrogen determinations on raw water to guide in the determination of chlorine dose requirements particularly during periods of raw water quality fluctuation.

Note: Pre-chlorination as used above is defined as the application of chlorine in such quantities as to obtain "free" chlorine residuals of at least 0.1 ppm after contact in the settling and detention basin.

7. Make routine laboratory and plant control check tests to assure that at least 0.1 ppm of the total observed residual chlorine is in the "free" state for greatest bactericidal effect.

8. Make analyses as necessary to determine the nature and extent of substances which might interfere with the accurate determination of the residual chlorine by the orthotolidine test and make adjustments as needed.

9. Investigate the installation of automatic chlorine residual recording equipment.

10. Maintain accurate turbidity standards up to 100 ppm at all times for plant control use at Lakewood.

Pertaining to Long Range Development of the Waterworks

11. Consider the installation of suitable pipe lines and connections to eliminate all takeoffs from the mains which lead from the Lakewood Station to Reservoir "A". Arrangements whereby all delivered water would pass through Reservoir "A" prior to delivery to the distribution system, would afford a larger measure of protection against fluctuations in raw water quality and greater flexibility in treatment than is provided at present. This recommendation should be given serious consideration when studies are made to design a parallel feeder main covering the three mile stretch which is now served by a single feeder.

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